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Ye. N. Romanova

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ABSTRACT: A method for calculating the redistribution of water from summer rains over undulating relief is provided. The method is used to determine the amount of water entering the soil over different sections of slopes. The amount of water absorbed by soil on slopes, and along their feet, is calculated for several points by type of soil.

The presence of moisture in the soil available for plants is one of the conditions necessary for the existence of plants. Insufficient moisture slows plant growth and development, and the plant will die if the soil is badly dried out, that is, when the entire store of productive moisture is gone. Excess moisture in the soil too has an unfavorable effect on plants. /66*

Climatic conditions, soil differences, and peculiarities in vegetation determine the reserves of moisture in the soil when the relief has been leveled for farm lands during similar agricultural practices. The reserves of moisture in the soil when the relief is broken depend greatly on the location of the sections under consideration, and this is in addition to the factors already mentioned. The moisture in the soil in these sections often changes to a much greater degree than is the case when making a transition from one climatic zone to another. Soil moisture at the peak of a hill, and along the upper slopes, in a very wet zone can be less than along the foot of a hill in a drier zone.

The reason for the uneven moisture over different sections of an undulating relief is the redistribution of precipitation, winter and summer. Snow usually piles up in depressions in the relief in the winter time, the result of the snow blowing down from higher elevations. The windward slopes also are bare of snow, but there is an increase in the snow cover on the lee slopes. The research done by M. Ya. Glebova [3] found that southerly, and southwesterly winds prevail during snowstorms over much of the European SSSR and Western Siberia, and that northerly winds are rare. This results in heavy snow cover on lee slopes with

* Numbers in the margin indicate pagination in the foreign text.

northern exposures, but the snow cover is not nearly as heavy on the southern, windward, slopes, where melting occurs.

The depth of the snow cover will change over the same slope, diminishing from the foot to the peak of the slope, but there will be large drifts on the upper parts of a lee slope.

We know that the absorption by the soil of melt-water from winter precipi- /67
tation depends on a combination of the snow melt and the thawing of the soil. The south slope sheds its snow much more rapidly than does the north, the result of the greater solar radiation it receives. Freezing of the soil on the slopes depends on the depth of the snow cover. The shallower the snow cover, the more solidly the soil freezes. There is little dependence between the thawing of the soil under the snow and the flux of radiation. The soil on the southern slope often thaws within a few days after it has shed its snow, yet on the north slope, where the snow melts slowly, the soil will thaw before it sheds its snow. The difference in the nature of snow disappearance and thawing of the soil on the north and south slopes is the result of the dissimilar absorption by the soil of melt-water. Data furnished by S. I. Taychinov and M. I. Fayzullin [9] show that the south slopes always absorb less water than the north slopes (Table 1).

TABLE 1. ABSORPTION BY THE SOIL OF WINTER PRECIPITATION ON NORTH AND SOUTH SLOPES (% OF WINTER RESERVE). BASHKIR PREURALS, CONVEX-CONCAVE SLOPE

Exposure	Section of slope	1952	1953
South slope	Lower	57.7	83.3
	Middle	32.0	63.5
	Upper	-	70.7
North slope	Lower	88.1	100.0
	Middle	68.2	80.8
	Upper	69.6	-

Thus, on the north slope, where the soil thaws before the snow disappears, the thaw-waters are 70-100% used, but on the south slope, where the snow disappears before the soil thaws, only 30-80% of the thaw-waters are used.

The spring wetting of the soil, the result of the redistribution of the winter precipitation, and the pecularities of the spring snow melt, create what is a characteristic relationship between soil moisture and the different relief forms for an undulating relief.

Wetting of the soil by summer rains too is different in different localities. Rain water will flow uniformly over the whole of a limited area, but after that redistribution begins. At the peaks of hills, and at a watershed, water from rain only will in part penetrate the soil, and the remainder will flow down the slope. On slopes, some of the rain water is absorbed by the slopes, and some flows down along the slopes, but here its arrival is increased compared to the peaks and the upper sections of slopes because of the water flowing from higher sections. The inflow of additional moisture on straight and concave slopes increases downslope, reaching maxima at the feet of the slopes, and in the valleys.

Many researchers have studied soil moisture in terms of locality. This work began at the end of the 19th and beginning of the 20th centuries.

S. I. Sil'vestrov [8] has provided quite a detailed evaluation of the conditions for the wetting of the soil over different sections of slopes in terms of /68 type of slope profile and exposure. However, the quantitative data on soil moisture at his disposal, cover slopes with a convex profile only. His data are qualitative for straight and concave slopes, and are based on visual observations of snow distribution and a qualitative estimate of solar radiation, evaporation, and runoff for different relief forms. Sil'vestrov's scheme (Table 2) is a more detailed qualitative scheme, encompassing all basic relief forms.

The obtaining of a similar quantitative scheme, based on experimental research, is very difficult because in addition to the huge volume of time-consuming work involved, the question is complicated by the selection of relief objects, comparable in terms of soil differences, agricultural practice, and nature of vegetation. If any one of these conditions is not met in the selection of the object, the results of the research will be unsuited for broad generalization.

A. P. Fedoseyev [10], and other researchers [8, 9], made their estimates of the wetting of individual relief forms by using a so-called wetness factor, that is, the ratio of reserves of moisture in the root zone of the soil for different relief forms to the reserves of moisture in a control section. This index should be recognized as satisfactory for establishing general behavior patterns. It is

TABLE 2. SCHEME OF RELATIVE CONDITIONS FOR WETNESS OF SOILS IN ACCORDANCE WITH TYPE OF SLOPE RELIEF

Type of beam drainage basin	Relative wetness conditions			
	highly inadequate	inadequate	increased	average
Slopes, convex profile	Lower parts of sunny (south, southeast, southwest) and windward slopes	Lower parts of (north, northwest) and lee slopes	Watershed plateaus and upper sections of slopes with all exposures	Average sections of slopes of all exposures
Slopes, straight profile	Upper half of sunny and windward slopes		Lower half of shaded and lee slopes	Rest of drainage basin area
Slopes, concave profile	Upper parts of sunny and windward slopes	Upper parts of shaded and lee slopes	Trains of shaded and lee slopes	Trains of slopes with other exposures
Slopes, complex profile	Middle parts of sunny and windward slopes	Upper parts of all slopes, middle parts of shaded slopes	Windward and shaded trains	Rest of trains

impossible to use absolute values of differences in moisture content in different localities for this purpose.

The wetness factor also can be used from year to year because of the change in the depth to which the soil freezes, the nonuniformity of the snow cover, nature of spring snow melt, and other factors. The general behavior patterns in /69 the change in the wetness factor are quite clear cut (Table 3), despite the complexity and inconsistency in the complex of phenomena that influence the redistribution of moisture in terms of relief forms. The wetness factors for different relief forms are not consistent, even when used by the same researcher. A. P. Fedoseyev, for example, has slopes in Tselinnyy Kray drier than they are in Alma Ata Oblast. There is not doubt that the variety of wetness factor values is the result of climatic features, slope characteristics, and weather conditions. Nevertheless, this method of estimating the wetness of different relief forms has its practical value.

A precise calculation of the reserve of moisture in the soil is one of the /70 necessary conditions for determining the moisture that can be provided for plants. Existing methods for estimating the wetness of soils are satisfactory only for open, level site conditions. S. A. Verigo, L. A. Razumova, et al., have done most of the generalizing in this field, down to the compilation of schematic maps of the distribution of productive soil moisture for the USSR. However, a very large percentage of our cultivated land has a rugged topography. According to the information above, soil wetness conditions for broken ground differ sharply from those for level ground, so it is obvious that the work done along these lines does not reveal the actual reserves of moisture in our soil. The estimate made using the wetness factor is a special one, and still is applicable only to individual regions. So it is apparent that this method will not be used in the future to generalize estimates of soil moisture under different relief conditions in the country as a whole because of the great volume of time-consuming work, and because of the variety of natural conditions prevailing. Another method for estimating the moisture reserves in the soil must be found, one that will permit us to discover the quantitative behavior pattern in their changes in different localities, and which, in combination with available data on reserves of moisture in the soil for a level site, will make it possible to estimate the wetness of the soil under different physical and geographic conditions.

TABLE 3. MEAN WETNESS FACTORS FOR DIFFERENT RELIEF FORMS

Observation site and relief form	Spring	Summer	Autumn	Mean	Author
Alma Ata Oblast					
Depression	1.46	1.58	1.15	1.40	Fedoseyev
North slope	1.12	1.22	0.98	1.11	
South slope	0.77	0.73	0.79	0.76	
Watershed plain	1.00	1.00	1.00	1.00	
Black earth steppe					
Level steppe		1.00			Ponagaybo
Edge of a minor depression (crest)		0.95			
Slope		1.21			
Bottom of a minor depression		1.30			
Zapadno-Kazakhstanskiy Kray					
Microsinks	1.38	0.88	0.84		Fedoseyev
Microslopes	1.13	0.89	0.90		
Tselinnyy Kray					
Tsurikovka					
Plain (flat)	1.00	1.00	1.00	1.00	Fedoseyev
Foot of south slope	0.93	0.93	0.96	0.94	
Northwest slope	0.75	0.76	0.58	0.71	
South slope	0.62	0.50	0.48	0.53	
Peak of a bald peak	0.55	0.46	0.34	0.46	
Moscow Oblast					
Foot of slope and flat		2.13	2.02		Mosolov
Lower part of slope		1.49	1.08		
Upper part of slope		1.06	0.98		
Leningrad Oblast					
North slope					
Peak	0.58	0.50	0.75	0.61	Romanova
Middle	1.00	1.00	1.00	1.00	
South slope					
Peak	0.52	0.64	0.69	0.62	Romanova
Middle	0.56	0.65	0.59	0.63	
Flat	2.18	2.16	1.99	2.11	

Pointed out above was the fact that the principal difference in soil moisture with respect to relief forms is attributable to the redistribution of precipitation over broken ground. The solution to the problem of a generalized estimate of the reserves of moisture in the soil can, in our view, be approached if this redistribution of precipitation is considered quantitatively, for this will permit us to determine the arrival of moisture at different sections of an undulating relief.

The values of evaporability and evaporation for different parts of the relief still must be determined in order to estimate the amount of moisture contained in the soil. The water balance equation for the summertime can, in fact, be written in the form

$$r - f = E + \omega$$

where r is the precipitation, f ix the runoff, E is the evaporation, and ω is the change in the content of moisture in the soil. The left side of the equation characterizes the arrival of moisture in the soil and changes considerably with relief forms as a result of different runoff conditions. This part of the equation therefore expresses the redistribution of precipitation under undulating relief conditions. If this magnitude, r - f, is found, and if E is determined, the change in the moisture contained in the soil, ω, will be known.

This paper is the first attempt to establish behavior patterns in the redistribution of summer rain along slopes, that is, to find r - f for different parts of a slope.

Let us consider the simplest case, that of the redistribution of summer rain over slopes with a straight profile, that is, slopes with a constant curvature over the extent of the slope. Let us divide the slope into n sections from top to bottom, and then let us trace the distribution of fãlling rain along the slope.

Section I, which includes the peak and upper part of the slope, is wet only by the rain.

Section II not only receives the falling rain, r, but additional moisture from Section I runoff. Here then, the arrival of water is equal to $r + \alpha r$, /71
where α is the runoff factor for the particular slope, that is, a magnitude indicating the part of the rain flowing down the slope.

Section III is obtained correspondingly as $r + \alpha r + \alpha^2 r$, and so on, to the n^{th} section, which receives $r + \alpha r + \alpha^2 r + \alpha^3 r + \ldots + \alpha^{n-1} r$ water.

The expression obtained is a geometric progression in which the first term is r and the denominator is an α progression. All that is required to determine the arrival of water, Q_n, at any point along the slope is to solve for it by using the formula for the sum of a geometric progression

$$Q_n = \frac{r(1-\alpha^n)}{1-\alpha}. \tag{1}$$

The rate of flow of rain water (the runoff) along the slope can be expressed similarly. Water in an amount equal to αr will flow off Section I. The equal to $(r + \alpha r)\alpha = \alpha r + \alpha^2 r$ will flow off Section II, which, in accordance with the foregoing, receives $r + \alpha r$ water, and flowing off Section III will be $\alpha r + \alpha^2 r + \alpha^3 r$, and so on. The section n flow will be $\alpha r + \alpha^2 r + \alpha^3 r + \ldots + \alpha^n r$.

This series is a geometric progression in which the first term is αr, and the denominator is α. Accordingly, the runoff at any point along slope f_n will be determined by the formula

$$f_n = \frac{\alpha r(1-\alpha^n)}{1-\alpha}. \tag{2}$$

The difference $(Q_n - f_n)$ goes to wetting the soil, that is, this moisture seeps into the soil. Calculating Eq. (2) from Eq. (1), we obtain the fact that the soil on any section of the slope will absorb a quantity of water equal to R_n

$$R_n = r(1-\alpha^n). \tag{3}$$

A good deal of summer rain seeps into the soil, even on the slopes, so slopes receive more moisture than would follow from Eq. (3).

The capacity of rain to seep into a particular type of soil will depend on the intensity and duration of the rain, and on soil wetness.

Agricultural patterns, and the condition of the vegetation, are highly important. Very light rain (≤ 0.1 mm per day) will be absorbed by the vegetation, and may not even reach the ground. Still such rain has a favorable effect on plants, "revitalizing" them. It need not, however, be considered when Eq. (3) is used.

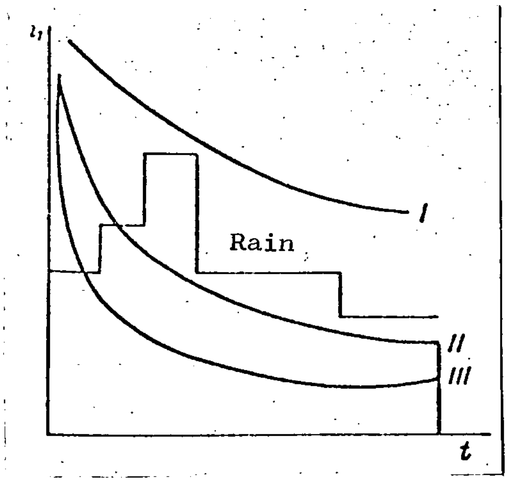

Figure 1. Influence of soil wetness on elementary runoff. Curves of seepage of water into the soil. I- dry soil; II- wet soil; III- very wet soil.

Heavy rain seeps into the soil and provides no runoff. Included here is rain, the intensity of which is less than the seepage intensity. This latter varies greatly with different soils and ground (from 0.05 mm/min to 18 mm/min, and more). Table 4 lists data on seepage.

If the rain intensity is less than the seepage intensity, and if it continues for a long time, the rain can saturate the soil, and the result will be runoff. This is a possibility in the summertime, and particularly in the fall, in regions with /72
excess and moderate wetness.

S. A. Verigo's data on reserves of moisture in the soil in the 0-50 cm layer were used to make a quantitative estimate of the possibility of this phenomenon, and A. V. Protserov's data [6] were used to calculate the moisture in the soil equal to the field water capacity in the same layer. The difference between these magnitudes characterizes the undersaturation of the soil, that is, the deficit in soil moisture. If the moisture deficit, taken as of the first day of the month, is significantly greater than the total rain for the particular month, rain runoff can occur only if the rain is heavier than seepage into the soil can handle. If the monthly rain exceeds the deficit, rain runoff can occur during any heavy rain. Table 5 lists the values we calculated for soil moisture deficit for a number of stations located in different physical and geographic zones for average lont-term data for four warm months (May, June, July, August). Observed virtually throughout the USSR at this time was an undersaturation of the 0-50 cm soil layer with moisture. It was very slight in the western and northwestern parts of the country (exceeded 20 mm), but at the beginning of the summer there even was some supersaturation. The undersaturation was 135-170 mm in the more /75
southern regions (Kuybyshev). The inadequacy of moisture increases throughout the country by the end of the summer.

An excess of moisture is a usual phenomenon in the summertime in individual, wetter years (Table 6). Even in Kuybyshev, rain somewhat exceeded the deficit

TABLE 4. SOIL AND GROUND CLASSIFICATION BY INTENSITY OF ABSORPTION (N. F. SRIBNYY)

Type	Soil and ground designations	Intensity of absorption, mm/min
I	Rocky unfissured ground, tundra soils, marshy soils, water-logged podzolic soils	0-0.05
II	Mountain meadow soils, podzolic soils of Primorskiy Kray, soils of mari basins, shallow mountain steppe soils on a rock base	0.1
III	Takyrs, salt bottoms and salt gardens, clays, fertile clay soils	0.2
IV	Podzolic loamy soils	0.3
V	Grey forest soils, leached and degraded chernozems, terrace chernozem	0.4
VI	Thick and fertile chernozem, podzolic sandy loam soils, clay sierozem	0.55
VII	Ordinary and southern chernozem, light chestnut and brown soil	0.7
VIII	Sierozems and podzolic sandy loam soils	0.85
IX	Chernozems, sandy loam and sandy	1.0
X	Dark chestnut and brown soils, sandy loam and sandy sierozems, well covered sands	1.2
XI	Comparatively lightly covered sands	1.5
XII	Blown uncemented sands	1.8 and greater

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TABLE 5. SOIL WETTING CHARACTERISTICS

Stations	Deficit of productive moisture in the soil				Precipitation				Deficit + Precipitation			
	V	VI	VII	VIII	V	VI	VII	VIII	V	VI	VII	VIII
Khibiny	—	—117	—131	—140	33	51	55	63		—66	—76	—77
Kargopol'	—100	—70	—86	—	46	60	64	72	—54	—10	—22	—
Vel'sk	—59	—103	—121	—140	47	65	66	64	—12	—38	—55	—76
Yefimovskaya	—41	—80	—110	—121	49	68	81	85	—8	—12	—29	—36
Belogorka	—	—73	—97	—103	48	69	68	91	—	—4	—29	—12
Priladoga	—97	—102	—	—103	48	69	67	88	—49	—33	—	—15
Bazlovo	—60	—68	—115	—98	50	77	91	89	—10	+9	—24	—9
Uglich	—38	—57	—87	—100	49	75	80	80	+11	+18	—7	—20
Rostov	—94	—113	—153	—140	42	66	69	70	—52	—47	—84	—70
Borovichi	—77	—111	—143	—140	46	64	75	75	—31	—47	—68	—65
Belyy	—46	—82	—108	—96	55	78	101	83	+9	—4	—7	—13
Batishchevo	—63	—91	—142	—142	53	76	86	79	—10	—15	—56	—63
Gorki	—97	—121	—158	—148	49	76	90	80	—48	—45	—68	—68
Minsk	—70	—109	—123	—96	55	84	88	83	—15	—25	—35	—13
Vasilevichi	—72	—99	—114	—118	59	81	101	70	—13	—18	—13	—48
Pochinki	—92	—110	—129	—123	41	69	86	74	—51	—41	—43	—49
Kostroma	—36	—93	—115	—135	40	68	61	77	+4	—25	—54	—58
Yelat'ma	—68	—93	—119	—113	46	64	77	61	—22	—29	—42	—52
Mikhaylov	—101	—125	—154	—151	36	52	67	48	—65	—73	—87	—103
Zhizdra	—49	—75	—107	—88	56	82	89	65	+7	+7	—18	—23
Novozybkov	—136	—145	—150	—	52	73	94	69	—84	—72	—56	—
Shatilovskaya	—77	—101	—122	—127	51	74	89	67	—26	—27	—33	—60
Ushakovo	—117	—151	—185	—191	49	67	67	53	—68	—84	—118	—138
Staryy Oskol	—156	—165	—188	—184	51	75	79	63	—105	—90	—109	—121
Bogoroditskoye-Fenino	—145	—160	—182	—184	49	70	72	59	—96	—90	—110	—125
Yaransk	—131	—156	—158	—172	35	47	55	49	—96	—109	—104	—123
Savali	—108	—130	—158	—141	38	58	53	56	—70	—72	—105	—85
Cheboksary	—110	—133	—157	—163	40	56	64	62	—70	—77	—93	—101

TABLE 5 (continued)

Stations	Deficit of productive moisture in the soil				Precipitation				Deficit + Precipitation			
	V	VI	VII	VIII	V	VI	VII	VIII	V	VI	VII	VIII
Kudymkar	—141	—128	—142	—162	49	63	65	66	—92	—65	—77	—96
Nozhovka	—120	—120	—130	—153	43	61	63	69	—77	—59	—67	—84
Perm'	—76	—83	—101	—115	51	66	79	72	—25	—17	—22	—43
Chernushka	—164	—174	—188	—202	47	71	75	63	—117	—103	—113	—139
Yelabuga	—113	—116	—151	—	37	56	57	48	—76	—60	—94	—
Kazan'	—104	—129	—152	—169	34	56	52	49	—70	—73	—100	—120
Menzelinsk	—108	—135	—157	—157	37	52	58	49	—71	—83	—99	—108
Chulpanovo	—159	—181	—216	—210	38	47	46	44	—121	—134	—170	—166
Aksakovo	—51	—75	—91	—125	39	42	52	39	—12	—33	—39	—86
Sterlitamak	—137	—163	—181	—181	40	50	56	50	—97	—113	—125	—131
Krasnyye Baki	—87	—97	—114	—111	42	66	69	61	—45	—31	—45	—50
Gor'kiy	—72	—94	—117	—125	40	61	74	58	—32	—33	—43	—67
Simbiley	—76	—89	—111	—136	40	61	68	54	—36	—28	—43	—82
Lukoyanov	—114	—138	—157	—159	42	56	81	55	—72	—82	—76	—104
Voronezh	—110	—134	—172	—172	55	69	68	59	—55	—65	—104	—113
Kamennaya Step'	—168	—198	—227	—228	46	59	71	63	—122	—139	—156	—165
Mitrofanovka	—164	—186	—214	—	49	63	63	46	—115	—123	—151	—
Pugachev	—188	—211	—227	—	28	30	28	32	—160	—181	—199	—
Atkarsk	—150	—175	—192	—200	43	54	52	40	—107	—121	—140	—160
Orlov Gay	—135	—152	—178	—	31	24	27	24	—104	—128	—151	—
Krasnyy Kut	—182	—219	—234	—236	27	34	27	28	—155	—185	—207	—208
Kuybyshev	—167	—184	—206	—210	29	39	38	36	—138	—145	—168	—174
Khar'kov	—144	—170	—206	—	49	69	62	55	—95	—101	—144	—
Buguruslan	—208	—223	—247	—247	34	44	44	40	—174	—179	—203	—207
Buzuluk	—142	—169	—214	—194	32	37	39	35	—110	—132	—175	—159
Rostov-na-Donu	—176	—210	—220	—227	48	70	54	38	—128	—140	—166	—189
Tselina	—162	—207	—213	—	40	59	51	34	—122	—148	—162	—
Kotel'nikovo	—143	—154	—181	—181	33	55	58	44	—110	—99	—123	—137
Zolotushka	—149	—182	—192	—189	72	92	78	53	—77	—90	—114	—136
Irbit	—139	—140	—163	—175	44	74	62	68	—95	—66	—101	—107
Kur'i	—118	—137	—157	—167	48	64	77	67	—70	—73	—80	—100

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in soil moisture in July 1944. There are individual years when nonuniformity in moisture during the summer is characteristic. July sometimes shows a greater abundance of moisture than is the case in June, but August usually is drier, even in the excess moisture zone. /75

The summer runoff is much less than the spring runoff for a mean long-term period in most regions of the country. There are individual years when the rain runoff can be compared with the spring runoff, and even can exceed it, as will be seen from Table 7, which shows that the rain runoff was very heavy for a plot in the village of Sobakino in 1927 and 1928. The data cited show that the estimate of the wetness of a territory must take the summer runoff into consideration. Conditions for runoff on slopes are more favorable than is the case for a level area because of the inclination of the surface. Rain water will flow down slopes, whereas this cannot happen in the case of level sections.

Let us pause to consider the effect of steepness of a slope on water absorption for different types of soils.

M. F. Sribnyy's data, listed in Table 8, show that water absorption will change 10 percent when slope steepness increases from 3° to 11.5°.

The runoff from slopes occurs because moisture absorption is less on the slopes when the precipitation occurs than is the case on level sections.

A. N. Befani [1] too notes the slight influence change in steepness of a slope has on the runoff, and considers it possible, in calculations dealing with rain runoff, to use a constant that includes slope steepness equal to 0.8. Table 4 lists data on the intensity of absorption by different types of soils and grounds on the level. The absorption value in this table obviously can be applied to slopes by introducing the factor 0.8. Moisture of the soil too has a great influence on absorbability.

Figure 1 [1] is extremely useful because it shows the influence of soil moisture on the elementary runoff from data provided by the Hydrological Laboratory in the village of Mayaki. According to this figure, when rains fall on very dry soil as shown it is completely absorbed (I), but when it falls on damp soil (II) much of it flows off, and almost all of it flows off when it falls on very wet soil (III).

TABLE 6. SOIL WETTING CHARACTERISTICS FOR INDIVIDUAL YEARS

Stations	Years	Deficit of productive moisture in the soil				Precipitation				Deficit + Precipitation			
		V	VI	VII	VIII	V	VI	VII	VIII	V	VI	VII	VIII
Khibiny	1939,	—	−64	−66	−86	24	42	66	30	—	−22	00	−56
	47	—	−102	−138	−142	21	37	58	54	—	−65	−80	−88
Kargopol'	1937	−109	−80	−113	−124	72	26	125	40	−37	−54	+12	−84
Vel'sk	1936,	—	−73	−107	−128	3	40	67	48	—	−33	−40	−80
	39	−45	−77	−71	−115	28	95	53	16	−17	+18	−18	−99
Yefimovskaya	1936,	−38	−46	−45	—	36	111	64	22	−2	+65	+19	—
	39	−81	−58	−65	−70	11	81	116	23	−70	+23	+51	−47
Belogorka	1947	−40	−90	−120	−148	13	64	73	73	−27	−26	−47	−75
Priladoga	1938	−90	−89	−124	−128	48	88	64	23	−42	−1	−60	−105
Bazlovo	1937,	−68	−65	−119	−41	50	32	154	56	−18	−33	+35	+15
	39	+46	+35	−47	−56	55	38	21	20	+101	+73	−26	−36
Uglich	1937,	−64	−58	−55	−57	52	27	176	16	−12	−31	+121	−41
	42,	—	−50	−65	−75	82	99	115	48	—	+49	+50	−27
	45	—	−10	−77	−54	27	85	123	61	—	+75	+46	+7
Rostov-na-Donu	1942,	−106	−80	−138	−110	33	101	82	55	−73	+21	−56	−54
	45	−102	−124	−109	−96	21	118	128	62	−81	−6	+19	−34
Borovichi	1941	−46	−78	−83	−134	32	34	57	32	−14	−44	−26	−102
Belyy	1937,	−92	−78	−131	−130	36	14	135	47	−56	−64	+4	−83
	39,	−9	−92	−165	−184	77	26	66	3	+68	−66	−99	−181
	40	−97	−127	−146	−157	34	48	73	105	−63	−79	−73	−52
Batishchevo	1937,	−74	−132	−183	−96	22	11	133	71	−52	−121	−50	−25
	40	−85	−138	−173	−116	36	36	172	64	−49	−102	−1	−52
Gorki	1938,	−85	−111	−103	−170	43	75	58	59	−42	−36	−45	−111
	40	−98	−106	−155	−144	49	22	80	170	−49	−84	−75	+26
Minsk	1938	−59	−94	−97	−66	27	45	149	55	−32	−49	+52	−11
Vasilevichi	1938	−54	−61	−101	−93	85	35	170	44	+31	−26	+69	−49
Kostroma	1939,	−23	−68	−103	−123	30	59	63	9	+7	−9	−40	−114
	42	−52	−75	−84	−87	53	62	142	34	+1	−13	+53	−53
Mikhaylov	1940,	−75	−112	−124	−105	6	71	92	75	−69	−41	−32	−30
	43,	−94	−139	−173	−107	48	23	133	25	−46	−116	−40	−82
	45	−94	−100	−114	—	64	92	48	126	−30	−8	−66	—
Shatilovskaya	1940	−83	−128	−142	−155	31	26	71	71	−52	−102	−71	−84
Ushakovo	1937	−113	−150	−121	−200	22	46	64	151	−91	−104	−57	−49
Staryy Oskol	1940	−162	−150	−188	−164	49	41	72	26	−113	−109	−116	−138
Bogoroditskoye-Fenino	1940	−133	158	−219	−172	42	34	126	45	−91	−124	−93	−127

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TABLE 6 (continued)

Stations	Years	Deficit of productive moisture in the soil				Precipitation				Deficit + Precipitation			
		V	VI	VII	VIII	V	VI	VII	VIII	V	VI	VII	VIII
Yaransk	1936,	—132	—154	—161	—191	24	21	65	13	—108	—133	—96	—178
	39	—84	—133	—173	—162	54	9	50	27	—30	—124	—123	—135
Savali	1947	—108	—103	—107	—122	37	73	126	41	—71	—30	+19	—81
Kudymkar	1941,	—	—91	—132	—182	74	89	36	37	—	—2	—96	—145
	42	—112	—135	—118	—157	57	112	75	40	—55	—23	—43	—117
Perm'	1942,	—105	—105	—72	—113	37	142	100	23	—68	+37	+28	—190
	45	—115	—80	—118	—93	44	56	62	58	—71	—24	—56	—35
Chernushka	1942	—171	—193	—146	—	54	72	81	48	—117	—121	—65	—
Aksakovo	1942,	—3	—35	—36	—103	51	82	119	22	+48	+47	+83	—81
	46,	—62	—51	—23	—85	56	29	92	46	—6	—22	+69	—39
	47	—36	—53	—56	—113	61	74	42	72	+25	+21	—14	—41
Sterlitamak	1947	—122	—129	—121	—170	57	30	38	95	—65	—99	—83	—75
Krasnyye Baki	1946	—87	—129	—99	—84	9	32	117	76	—78	—97	+18	—8
Gor'kiy	1945	—95	—99	—73	—63	56	145	173	126	—39	+46	+100	+63
Simbiley	1945	—88	—88	—91	—	40	82	95	56	—48	—7	+4	—
Lukoyanov	1937	—84	—120	—154	—164	79	120	70	87	—5	0	—84	—77
Mitrofanovka	1940,	—158	—208	—191	—	32	14	144	52	—126	—194	—47	—
	41	—148	—151	—200	—147	80	99	117	75	—68	—52	—83	—72
Atkarsk	1937,	—139	—167	—175	—192	45	103	58	56	—97	—64	—117	—136
	40	—142	—169	—158	—200	11	96	58	17	—131	—73	—100	—183
Orloy Gay	1944,	—124	—130	—176	—	31	53	52	20	—93	—77	—124	—
	46	—115	—148	—155	—	48	26	68	4	—67	—122	—87	—
Krasnyy Kut	1942	—171	—190	—181	—228	84	114	71	7	—87	—76	—110	—221
Kuybyshev	1942,	—131	—160	—148	—217	58	96	86	6	—73	—64	—62	—211
	44	—	—158	—156	—149	49	62	159	38	—	—96	+3	—111
Buguruslan	1947	—204	—178	—222	—221	63	34	74	70	—141	—144	—148	—151
Tselina	1941	—142	—163	—194	—160	97	83	75	75	—45	—80	—119	—85
Kotel'nikovo	1941	—133	—144	—173	—176	80	98	29	89	—53	—43	—144	—87
Zolotushka	1939,	—	—173	—204	—156	52	135	84	132	—	—38	—120	—24
	40	—133	—175	—141	—	85	107	152	27	—48	—68	+11	—
Irbit	1942,	—144	—132	—138	—154	41	107	119	35	—103	—25	—19	—119
	44,	—112	—160	—168	—159	29	60	97	89	—83	—100	—71	—70
	47	—146	—157	—142	—143	83	86	150	134	—63	—71	+8	—9
Kur'i	1943,	—	129	—95	—112	56	134	95	153	—	+5	0	+41
	45,	—110	—133	—154	—173	81	118	86	26	—29	—15	—68	—147
	47	—100	—127	—144	—160	44	89	129	100	—54	—38	—15	—60

Runoff from slopes with different exposures will differ too. Northern slopes, being wetter, are characterized by greater quantities of flowing waters, followed by the eastern and western slopes, and then by the southern, drier, slopes where least quantities of flowing waters are found [2, 10].

Befani [1] introduces values for a factor characterizing runoff soil moisture and type. This factor, η, is included in the runoff formula suggested by Befani in the following manner

$$\sigma = 0{,}8\eta h^{0{,}13} T^{-0{,}1},$$

where h is rain intensity, T is time it falls. Values of η are listed in Table 9, where we see that for sandy ground the heaviest runoff occurs from the wettest soil, and decreases as the soil dries. The heaviest runoff is from the drier /78
soils in the case of clay grounds, because of the peculiarities of the soil structure.

TABLE 7. RUNOFF FROM A PLOT IN THE VILLAGE OF SOBAKINO (mm). PODZOLIC SOIL.

Surface	1925		1926		1927		1928	
	snow	rain	snow	rain	snow	rain	snow	rain
Arable land	35,84	0,93	111,12	18,87	67,0	58,41	38,93	64,42
Fallow land	36,15	0,08	73,79	9,84	39,1	28,52	19,5	0,32

Commas represent decimal points.

TABLE 8. INFLUENCE OF SLOPE STEEPNESS ON WATER ABSORPTION BY DIFFERENT TYPES OF SOIL (%)

Slope steepness	Type soils		
	podzolized sandy loam	deep chernozem	forest loams and terrace chernozems
3°	0,55	0,72	0,77
6°	0,60	0,75	0,80
8°30′	0,60	0,80	0,85
11°30′	0,65	0,85	0,87

Commas represent decimal points.

TABLE 9. VALUES OF THE FACTOR η

Soil moisture in the 0-50 mm layer	Type ground			
	sandy	deep sandy loam	loam	clay
Saturated soil (90-100% of total porosity)	0,204	*0,59*	*0,69*	*0,82*
Field water capacity (70-80%)	0,102	0,225	0,265	0,36
Normal (50-60%)	0	0,092	0,123	0,170

Note. The less reliable data are in italics.

Commas represent decimal points.

Rain heavier than soil can absorb will result in runoff, even from slightly damp soils, and will wet slopes according to the results obtained using Eq. (3). But soil can receive medium intensity rain that will soak in completely. These rains wet different sections of the terrain uniformly and to a known degree help smooth out the relative differences in the wetting of individual sections of an /79 undulating relief. In very dry regions, where the runoff from summer rains is a very rare occurrence, even on slopes, the difference in the moisture in the soil under undulating relief conditions is almost entirely the result of the redistribution of winter precipitation and the pecularities of the spring snow melt. In these cases, the maximum differences in soil moisture occur in the spring, immediately after the snow melts. Differences in soil moisture gradually smooth out as moisture is consumed by plants during the growing season.

If showers are a rare occurrence in what is considered to be a reasonably wet region, and if the precipitation is of medium intensity, the relative difference in the moisture of the soil for the different relief forms will be less during the growing period if the soil is holding enough moisture accessible to the plants because there is no summer redistribution of rain in different localities.

In regions with frequent showers, and even when the reserves of moisture in the soil are less, these differences can occur throughout the growing period because the summer rains will be distributed over the territory nonuniformly.

So, it follows that Eqs. (1), (2), and (3) include only that part of the rainfall that necessarily produces runoff, and not the total rainfall. This precipitation will be designated r_r. The mean rainfall intensity, $\bar{r}$, is added to the redistributed moisture alike over all sections; that is, the moisture entering the soil as a result of summer rains over any section of the slope can be given as

$$R_n = \bar{r} + r_r(1 - \alpha^n). \tag{4}$$

Slope length too has an influence on wetting of the slope. In the case of comparatively dry soils, when their absorbability is high, long slopes are wetted better by summer rains than short slopes. A. I. Reshetnikov [7] observed the summer runoff from plots with identical slopes, but of different lengths (Valdayskaya Highland). He found that the volume of rainwater runoff from a plot 10 meters long was the same as that from one four times as long, and that the surface runoff from dry soils occurred over a stretch approximately 10 meters long, but that the flowing water was completely absorbed over longer stretches. Accordingly, when making a comparatively evaluation of soil moisture for similar sections of a slope (the center sections of slopes, for example) their extent too must be included, because long slopes wet better than short ones. The wetting of adjacent depressions under these conditions does not, on the other hand, depend on slope length.

In the case of well-wetted soils, when the volume of the slope runoff is proportional to the length of the slope, the difference in moisture along the slope will be less and soil moisture for similar sections of slopes with different lengths can be compared. Here, however, the moisture in the soil of adjacent depressions does depend on slope length. Depressions close to long slopes will be too wet and will not be favorable to plant growth.

The following conclusion can be drawn. Slope runoff does not depend on slope length in the case of dry soils, but the moisture in the soil on slopes will be proportional to their length, and the moisture in the soil of adjacent /80
valleys does not depend on slope length. The moisture in the soil on slopes with well-wetted soils, where the volume of the slope runoff is proportional to slope length, has very little to do with slope length, and the excess moisture in valleys will increase with increase in slope length. Once again we see that it

is necessary to apply such characteristics as the wetness factor with care, and that we must make the length factor for slopes more precise.

Data on the amount of precipation, and its intensity, are necessary in order to make a quantitative estimate of the moisture entering the soil from summer rains. This information can be obtained from weather station observations. It is more difficult to find the factor α, characterizing the degree of absorption of precipitation by soil on slopes. The magnitude of this factor depends on type of soil, its wetness, intensity of precipitation, and finally, on slope steepness. The literature on the subject contains fragmentary and unrelated information on this factor, obtained experimentally during field, or laboratory, investigations [1, 4, 7]. All these materials went into the compilation of a table of α factor values (Table 10).

TABLE 10. α FACTOR VALUES

Slope steepness degrees	Soils with moisture close to that of field water capacity				Soils with normal moisture			
	Rainfall intensity, mm/min							
	0,05	0,10	0,35—0,70	1,0—2,0	0,05	0,10	0,35—0,70	1,0—2,0
	Sandy loams, deep fertile chernozems							
3	0,45	0,50	0,60	0,65	0,10	0,15	0,20	0,35
5	0,50	0,55	0,65	0,70	0,10	0,15	0,20	0,40
7	0,50	0,55	0,65	0,70	0,15	0,20	0,25	0,40
9	0,55	0,60	0,70	0,75	0,15	0,20	0,25	0,45
12	0,55	0,65	0,70	0,75	0,15	0,20	0,25	0,45
	Loams, clay soils, leached and degraded chernozems							
3	0,55	0,60	0,70	0,75	0,25	0,35	0,40	0,55
5	0,60	0,65	0,75	0,80	0,30	0,40	0,45	0,60
7	0,60	0,65	0,75	0,80	0,30	0,40	0,45	0,65
9	0,65	0,70	0,80	0,85	0,35	0,45	0,50	0,65
12	0,65	0,70	0,80	0,85	0,35	0,45	0,50	0,70

Because available data were inadequate if the table were to be filled in completely, there were many cases when resort was had to interpolation and to certain generalizations. Specifically, the data listed in Table 4 as to the intensity of absorption by different soils was taken into consideration when classification by types of soils was undertaken. Available experimental data on α were extended to other types of soils characterized by exactly, or very nearly, the same intensity of absorption of water by the soil. Relative change in η was included when soils

TABLE 11. ABSORPTION OF WATER BY SOIL FOR NORMAL MOISTURE IN DIFFERENT PARTS OF THE RELIEF (kg/10 m^2) IN THE SUMMERTIME (I) AND ON A PLAIN (II)

Part of relief	Part of slope in meters from peak	Sandy loam $\alpha = 0,20$		Loam $\alpha = 0,45$		Sandy loam $\alpha = 0,60$		Loam $\alpha = 0,70$		Degraded chernozem $\alpha = 0,45$	
		I	II	I	II	I	II	I	II	I	II
		Minsk, 1938				Perm', 1942				Kuybyshev, 1944	
Peak and upper part of slope	0—10	1350	0,90	1105	0,74	640	0,64	580	0,58	1230	0,77
Middle part of slope	10—20	1462	0,98	1350	0,90	784	0,78	706	0,71	1430	0,90
Middle part of slope	20—30	1483	0,99	1427	0,96	868	0,87	796	0,80	1518	0,95
Lower part of slope	30—40	1490	1,00	1462	0,98	922	0,92	862	0,86	1558	0,98
Lower part of slope	40—50	1490	1,00	1462	0,99	952	0,95	904	0,90	1574	0,99
Foot of slope		1665	1,12	2057	1,38	1434	1,43	1758	1,75	2238	1,43
Plain		1490	1,00	1490	1,00	1000	1,00	1000	1,00	1590	1,00

Commas represent decimal points.

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were classified in terms of soil moisture. There is no questioning the fact that α is in need of further refinement. However, the values listed in Table 10 should be recognized as sufficiently reliable and suitable for use in evaluating the moisture in soils under undulating relief conditions, at least as a first approximation. /82

Let us cite some examples of the moisture calculation for different relief forms.

Minsk, July 1938. We found the water absorbed by a slope with a steepness of 7-10°, 50 meters in length, using the above procedure. 159 mm of rain fell in July, 79 mm of which were gentle in intensity and provided no runoff along the slope, but 80 mm were intense, and some of this ran down the slope. Soil moisture was very nearly normal. Table 11 lists α values 0.20 and 0.45 for sandy loam and loamy slopes, respectively. The slope was divided up along its length into 5 sections, each 10 meters long and 1 meter wide. The results of the calculations are listed in Table 11, and show that the wetness factors on a sandy loam slope are 0.90, 0.98, 0.99, 1.00, 1.12, and 0.74, 0.90, 0.96, 0.98, 0.99, 1.38 on a loamy slope. Similar calculations were made for other points, as well as for straight slopes with a steepness of 7-10° (Table 11).

The data in the table clearly show the influence exerted by type of soil. Sandy loam soils absorb much more water than do loamy soils, with the result that the moisture in different parts of sandy loam slopes is much more uniform than on loamy slopes, the upper parts of which are much drier than the plains. The feet of loamy slopes, on the other hand, receive much more water than do the feet of the sandy loam slopes.

So, on the basis of consideration of the redistribution of precipitation along a slope, we have obtained an expression enabling us to determine the quantity of water entering the soil on different parts of a slope, and at its foot.

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